Shark Bowl Working Document
SB/02/12

ANALYSIS OF CATCH RATE SERIES FOR LARGE COASTAL SHARKS

Enric Cortés

NOAA Fisheries
Southeast Fisheries Science Center
Panama City Laboratory
3500 Delwood Beach Drive,
Panama City, FL 32408, USA

June 2002

Summary

This document examines catch rate series of large coastal sharks that became available for this evaluation. The series include data from three fishery-independent surveys and two fishery-dependent programs: the NMFS longline survey in the northeast region, the South Carolina Department of Natural Resources longline survey, the NEFSC bottom trawl survey, the directed shark longline observer program, and the MRFSS recreational survey. A total of 41 series for large coastal sharks were examined: 8 series for the large coastal shark complex, 8 for sandbar shark, 7 for blacktip shark, 6 for dusky shark, 4 for the hammerhead shark genus, 4 for bull shark, 2 for tiger shark, 1 for scalloped hammerhead, and 1 for silky shark. Five of the series were subjected to the same Generalized Linear Model (GLM) standardization methodology to adjust for factors that affect relative abundance. The approach used to estimate relative abundance indices was a Generalized Linear Mixed Model that treats separately the proportion of sets with positive catches (i.e., where at least one shark was caught) assuming a binomial error distribution with a logit link function, and the catch rates of sets with positive catches assuming a Poisson error distribution with a log link function. Statistical analysis of trends in CPUE series revealed that there were eight significantly negative slopes and four significantly positive slopes for large coastal sharks and individual species, all of which were nominal, except for one.

ANALYSIS OF CATCH RATE SERIES AND TRENDS

Data Sources

A total of 41 catch rate series for large coastal sharks were examined. The series include data from three fishery-independent surveys and two fishery-dependent programs: the NMFS longline survey in the northeast region (NMFS LL NE), the South Carolina

Department of Natural Resources longline survey (SC LL), the NEFSC bottom trawl survey (NEFSC Bottom Trawl), the directed shark bottom longline observer program (Shark Observer), and the MRFSS recreational survey (MRFSS1 and MRFSS2). Of the 41 series examined, 8 were for the large coastal shark complex, 8 for sandbar shark, 7 for blacktip shark, 6 for dusky shark, 4 for the hammerhead shark genus, 4 for bull shark, 2 for tiger shark, 1 for scalloped hammerhead, and 1 for silky shark. Several of the series (SC LL and NEFSC Bottom Trawl) were subjected to a Generalized Linear Model (GLM) standardization methodology to adjust for factors that affect relative abundance. Two of the sets of series (NMFS LL NE and Shark Observer) are means of set-by-set information, whereas the MRFSS sets are aggregated totals of catch divided by effort by year. The extent of the geographical and temporal coverage varied among the series analyzed.

Fishery-independent Series

NMFS Narragansett Longline Survey (NMFS LL NE). This survey is conducted out of the northeast region by personnel from the NMFS NEFSC Narragansett (Rhode Island) Laboratory. Series for the large coastal shark complex, sandbar, blacktip, dusky, tiger, and scalloped hammerhead were reported in NMFS (1998) covering 1986, 1989, 1991, 1996, and 1998. These series are updated here to include 1996, 1998, and 2001 only. The 1996, 1998, and 2001 surveys were conducted at the same time of year (spring) as the 1989 and 1991 surveys, but used bottom longline gear vs. the pelagic gear that was used in the 1986 and 1989 surveys. The 1986 survey was conducted in the summer and, as in the 1998 SEW, it is believed not to be comparable to the later years for the simplified analysis undertaken here. The 2001 survey repeated 85 stations from the 1998 survey. This survey utilized monofilament longline gear deployed along the U.S. Atlantic coast, from Florida to southern New England. The data were not subjected to any GLM analysis for standardization; they represent annual averages, expressed as number of sharks caught per 100 hooks. One series was added for the silky shark.

South Carolina Department of Natural Resources Longline Survey (SC LL). Three short series from this survey were presented in NMFS (1998). They are augmented herein to include the period 1995-2001. This survey utilizes monofilament longlines set in coastal waters of South Carolina monthly from January to December. The target species for this survey is red drum, although sharks of several species are commonly caught. Data were available for the large coastal shark complex and sandbar shark. Catch rates are expressed on a set basis, which consists of 120 hooks on 6000 feet of mainline, with an average soak time of 0.75 hours (Glenn Ulrich, South Carolina Department of Natural Resources, pers. comm.). The data set received allowed the series to be subjected to GLM analysis to account for spatio-temporal factors that can affect relative abundance.

Northeast Fisheries Science Center Bottom Trawl Survey (NEFSC Bottom Trawl). Time series from this survey were not examined for the 1998 SEW (NMFS 1998).

The Northeast Fisheries Science Center in Woods Hole has been conducting spring and autumn bottom trawl surveys since 1968 and 1963, respectively. These surveys use stratified random sampling in depths ranging from 5 to 200 fathoms, from Cape Hatteras, North Carolina to well beyond the Canadian border. About 300 0.5-hour trawl sets are made at randomly chosen stations during each individual survey. Catch rates are thus expressed on a tow (=set) basis. The accumulated trawl survey data set contains information on over 27,000 sets. Some species of sharks susceptible to the bottom trawl gear are caught as bycatch in this survey. Data were available for sandbar shark and the large coastal shark complex. The series were subjected to GLM analysis.

Fishery-dependent Series

Bottom Longline Shark Observer Program (Shark Observer). Several series from this observer program were presented in NMFS (1998). They are augmented herein to include the period 1994-2001, based on information from the directed commercial shark bottom longline fishery observer program (G. Burgess, U. of Florida, pers. comm.). This NMFS-sponsored observer program covers vessels targeting large coastal sharks in the Gulf of Mexico and South Atlantic regions, especially off Florida, Georgia, and South and North Carolina. Vessels in this fleet use monofilament longline gear to catch sharks. Numerous species of sharks are landed in this fishery depending on season and area. Annual means, expressed as number of sharks caught per 10000 hook-hours, are presented.

Marine Recreational Fisheries Statistics Survey (MRFSS). Several series from this NMFS recreational survey were presented in NMFS (1998). They are augmented herein to include the period 1981-2000 or 2001. The series were split into two periods: 1981-1993 and 1994-2000 or 2001 to account for the implementation of recreational fishery regulations on large coastal sharks in 1993. For each period, two catch rate series were considered: one that used type A and B1 catch and effort estimates (MRFSS1) and one that used type A, B1, and B2 catch and effort estimates (MRFSS2). Type A estimates include catch that is available for identification, B1 is unavailable catch used for bait, filleted, discarded dead or other, and type B2 is unavailable catch that is released alive. The MRFSS survey covers a very large geographical area in the coastal U.S. Gulf of Mexico and south and mid-Atlantic regions. The series presented are aggregated totals of catch divided by effort in each year. Series were available for the large coastal complex, sandbar, blacktip, dusky, hammerhead sharks, and bull shark.

CPUE Standardization Methodology

Standardized catch rates for the large coastal shark complex or individual species were developed using generalized linear mixed models for the SC LL and NEFSC Bottom Trawl data sets. Because these data sets are from fishery-independent sources, where the methodology is standardized, many of the fishery operational variables that affect relative abundance estimates in analyses of fishery-dependent data sets needed not be included in the present analysis. Explanatory variables included in the data sets received for the present analysis included season and area (geographical or depth) only. Note that these surveys do not target sharks specifically and, in the case of the NEFSC Bottom Trawl survey, contain a large proportion of sets with 0 catches. For this latter survey, the data set had to be truncated by eliminating levels of the explanatory variables (e.g., specific years) from the analysis to avoid over-parameterization of the model and lack of convergence of the algorithm. Final models thus typically contained few variables and no interaction terms were included because of the reasons given above.

The approach used to estimate relative abundance indices was a Generalized Linear Mixed Model that treats separately the proportion of sets with positive catches (i.e., where at least one shark was caught) assuming a binomial error distribution with a logit link function, and the catch rates of sets with positive catches assuming a Poisson error distribution with a log link function. The models were fitted with the SAS GENMOD procedure (SAS Institute Inc. 1999) using a forward stepwise approach in which each potential factor was tested one at a time. Initially, a null model was run with no explanatory variables (factors). Factors were then entered one at a time and the results ranked from greatest to smallest reduction in deviance per degree of freedom when compared to the null model. The factor which resulted in the greatest reduction in deviance per degree of freedom was then incorporated into the model if two conditions were met: 1) the effect of the factor was significant at least at the 5% level based on the results of a Chi-Square statistic of a Type III likelihood ratio test, and 2) the deviance per degree of freedom was reduced by at least 1% with respect to the less complex model. The year factor was always included because it is required for developing a time series.

Results were summarized in the form of deviance analysis tables including the deviance for proportion of positive observations and the deviance for the positive catch rates. Once the final model was selected, it was run with a computer program that utilizes the SAS GLIMMIX macro (which fits generalized linear mixed models using the SAS MIXED procedure; Wolfinger, SAS Institute Inc.). Goodness-of-fit criteria for the final model included Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion, and –2* the residual log likelihood (-2Res L). The significance of each individual factor was tested with a Type III test of fixed effects, which examines the significance of an effect with all the other effects in the model (SAS Institute Inc. 1999). The final mixed model calculated relative indices as the product of the year effect least squares means (LSMeans) from the binomial and Poisson components using bias correction terms to calculate confidence intervals.

Trend Analysis

Linear regressions were fitted to the CPUE series. The dependent variable (catch rate) was sometimes log-transformed to improve the fit between CPUE and time (independent variable). The positive or negative trend of the slope and whether it was significant was noted.

Results and Discussion

Nominal Catch Rates

Nominal catch rates are presented in Figures 1 and 2 (NMFS LL NE), Figures 3 and 4 (Shark Observer), and Figures 5 and 6 (MRFSS1 and MRFSS2). The proportion of type A+B1 vs. type B2 by species and year for the MRFSS survey is presented in Table 1.

Standardized Catch Rates

SC LL Indices. Months were pooled into seasons (winter, spring, summer, and fall) and sampling locations, which were originally too numerous to include in the analysis, were pooled into four major areas. About 38%, 16%, and 11% of the sets analyzed encountered large coastal sharks, sandbar shark, and blacktip shark, respectively. The proportion of positive catches for the large coastal complex, sandbar, and blacktip shark was explained in each case by the season and year, area and year, and year and season factors, respectively (Tables 2-4). The mean catch rates for positive catches were explained by the area and season factors for the large coastal complex (Table 2), season and area for sandbar shark (Table 3), and year for blacktip (Table 4). Despite not being significant (P=0.0774 for the large coastal complex, Table 2; P=0.4922 for sandbar shark, Table 3), the year factor was included to develop the time series. Factors in the final model for the large coastal complex were significant, except for the year factor for both proportion positive and positive catches (Table 2). For sandbar shark, only the year factor in the positive catches was not significant (P=0.2979; Table 3), whereas for blacktip shark all factors were significant (Table 4). The relative standardized catch rates showed very similar trends to those of the nominal values for the three series, with all nominal values falling inside the 95% confidence limits of the standardized series (Figure 7).

NEFSC Bottom Trawl. Several years of data and one season were eliminated from the analyses because there were no observations of sets with positive catches for those factors. This resulted in the algorithm for CPUE standardization not being able to converge. Months were also pooled into seasons (winter, spring, summer, and fall) to allow standardization of catch rates and depth zones into four general categories. For the large coastal shark complex, years 1967-1971 and spring were eliminated; for sandbar shark, the same factors and 1978 were removed to allow for the analysis to proceed. Only about 1.5% and 1.2% of the sets analyzed encountered large coastal and sandbar shark, respectively.

The proportion of positive catches for the large coastal shark complex was explained by the depth zone, year, and season factors in that order (Table 5), whereas for sandbar shark the explanatory variables were depth zone and year (Table 6). However, only the depth zone and year factors were used in the final mixed model for the large coastal complex to allow the algorithm to converge. The mean catch rate for positive catches was also explained by the depth zone and year factors for the large coastal complex (Table 5) and by year and depth zone for sandbar shark (Table 6) in the final mixed model.

For the large coastal shark complex, the trend of the relative standardized catch rates was very similar to that of the nominal values, but the scale was offset in the early part of the time series, and in 1980 the nominal value did not fall within the 95% CL of the standardized value (Figure 8). Something analogous occurred with the trends of the standardized vs. nominal series for sandbar shark, with the 1983 nominal falling outside the 95% CL of the corresponding standardized value. For the two time series, the proportion of sets with positive catches was very low in most years due to the very large number of tows conducted in this survey and the scarcity of large coastal sharks caught as bycatch.

Trend Analysis

Four of the eight series available for the large coastal shark complex showed a declining trend in catch rates, all statistically significant at the 1% and 5% levels (Table 7). Of the four series that showed a positive trend, only the Shark Observer series was statistically significant (1% level). This series had also the steepest slope (11%), whereas the largest statistically significant annual rate of decrease was about 6% (NEFSC Bottom Trawl survey).

Four of the eight series for sandbar shark also exhibited a declining trend, but only two had a significantly negative slope (5% and 1% level). Of the four series showing a positive trend, none had a significantly positive slope. For blacktip, three of the seven series exhibited negative slopes, but none was statistically significant. Of the six series available for dusky shark, three had negative slopes and three had positive slopes, one of which (NMFS LL NE) was very steep and significant (5% level; but keep in mind that this series consists only of 3 points). For tiger shark, both series examined had positive slopes, but only one was significant (5% level; Shark Observer). For sharks of the hammerhead genus all four series (MRFSS) showed declining trends: the two MRFSS2 series (type A+B1+B2 catch) had statistically significant slopes at the 1% (for the 1981-1993 series) and 5% (1994-2000) level, respectively. All four recreational series for bull shark had negative slopes, but none was statistically significant. The NMFS LL NE series for scalloped hammerhead had a steep, significant (5% level) positive slope, and the NMFS LL NE series for silky was positive, but not significant.

In all, there were eight significantly negative slopes and four significantly positive slopes for large coastal sharks and individual species. It must be noted that all of the statistically significant series were nominal, except for the NEFSC Bottom Trawl series, which showed a negative slope for the large coastal complex. Two of the four series with significantly positive—and steep—slopes were from the NMFS LL NE survey, which consisted of only 3 points for the present analysis. The other two significantly positive series were from the Shark Observer program, but this fishery-dependent data set has not been standardized.

Acknowledgements

I thank the following individuals for making their data sets available: N. Kohler and L. Natanson for NMFS LL NE, G. Ulrich for SC LL, J. Galbraith for NEFSC Bottom Trawl, G. Burgess, A. Morgan, and T. Curtis for Shark Observer, and G. Scott and P. Phares for MRFSS.

References

SAS Institute Inc. 1999. SAS/STAT User's Guide, version 8. Carey, NC: SAS Institute Inc., 1999. 3884pp.

Table 1. Proportion of type A+B1 catch (A: catch available for identification; B1: unavailable catch used for bait, filleted, discarded dead or other) and type B2 catches (B2: unavailable catch released alive) from MRFSS survey data for large coastal sharks, sandbar, blacktip, hammerhead (genus), dusky, and bull shark.

	Large coastal		Sandbar		Blacktip	
Year	Type B2	Type A+B1	Type B2	Type A+B1	Type B2	Type A+B1
1981	0.73	0.27	0.48	0.52	0.80	0.20
1982	0.62	0.38	0.91	0.09	0.42	0.58
1983	0.72	0.28	0.71	0.29	0.68	0.32
1984	0.74	0.26	0.86	0.14	0.71	0.29
1985	0.56	0.44	0.75	0.25	0.33	0.67
1986	0.70	0.30	0.77	0.23	0.51	0.49
1987	0.66	0.34	0.85	0.15	0.40	0.60
1988	0.64	0.36	0.66	0.34	0.39	0.61
1989	0.49	0.51	0.58	0.42	0.31	0.69
1990	0.61	0.39	0.56	0.44	0.57	0.43
1991	0.56	0.44	0.71	0.29	0.46	0.54
1992	0.75	0.25	0.74	0.26	0.74	0.26
1993	0.73	0.27	0.80	0.20	0.63	0.37
1994	0.85	0.15	0.82	0.18	0.86	0.14
1995	0.82	0.18	0.77	0.23	0.69	0.31
1996	0.81	0.19	0.75	0.25	0.70	0.30
1997	0.85	0.15	0.79	0.21	0.71	0.29
1998	0.87	0.13	0.84	0.16	0.85	0.15
1999	0.90	0.10	0.87	0.13	0.73	0.27
2000	0.92	0.08	0.90	0.10	0.85	0.15

	Hammerheads		Dusky		Bull	
Year	Type B2	Type A+B1	Type B2	Type A+B1	Type B2	Type A+B1
1981	1.00	0.00	0.09	0.91	0.71	0.29
1982	0.56	0.44	0.62	0.38	0.02	0.98
1983	0.09	0.91	0.52	0.48	0.00	1.00
1984	0.64	0.36	0.24	0.76	0.00	1.00
1985	0.40	0.60	0.84	0.16	0.30	0.70
1986	0.76	0.24	0.84	0.16	0.93	0.07
1987	1.00	0.00	0.18	0.82	0.44	0.56
1988	1.00	0.00	0.66	0.34	0.42	0.58
1989	1.00	0.00	0.69	0.31	0.25	0.75
1990	0.73	0.27	0.45	0.55	0.31	0.69
1991	0.75	0.25	0.72	0.28	0.70	0.30
1992	0.91	0.09	0.51	0.49	0.53	0.47
1993	1.00	0.00	0.39	0.61	0.69	0.31
1994	0.92	0.08	0.70	0.30	0.75	0.25
1995	0.86	0.14	0.41	0.59	0.34	0.66
1996	0.96	0.04	0.60	0.40	0.49	0.51
1997	0.99	0.01	0.67	0.33	0.90	0.10
1998	0.98	0.02	0.75	0.25	0.83	0.17
1999	1.00	0.00	0.70	0.30	0.15	0.85
2000	0.93	0.07	0.96	0.04	0.15	0.85

Table 2. Deviance analysis tables showing the stepwise procedure used to develop the catch rate model for the**large coastal shark** aggregate in the South Carolina DNR longline survey. Proportion positive assumed a binomial error distribution, whereas positive catch rates assumed a Poisson distribution.

SCDNR LL

Proportion positive

Factors	**d.f.**	**Deviance**	**Deviance/df**	**% Reduction in deviance/df**	**% Difference**	**L**	**Chi Square**	**Pr>Chi Square**
NULL	727	967.23	1.3304			-483.61		
SEASON	725	945.07	1.3036	2.01	2.01	-472.54	22.15	<0.0001
AREA	724	958.86	1.3244	0.45		-479.44	8.34	0.0394
YEAR	721	957.12	1.3275	0.22		-478.56	10.11	0.1203
SEASON +								
YEAR	719	934.31	1.2995	2.32	0.31	-467.16	10.76	0.0961
AREA	722	941.87	1.3045	1.95		-470.94	3.20	0.3614
SEASON+YEAR+								
AREA	716	932.16	1.3019	2.14	-0.18	-466.08	2.15	0.5419

FINAL MODEL RESULTS

Factors	**Akaike's information criterion**	**Schwarz's Bayesian criterion**	**-2 Res L**	**Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor** SEASON	YEAR
SEASON+YEAR	3172	3176	3170	<0.0001	0.1055

Positive catches

Factors	**d.f.**	**Deviance**	**Deviance/df**	**% Reduction in deviance/df**	**% Difference**	**L**	**Chi Square**	**Pr>Chi Square**
NULL	276	218.55	0.7918			-199.92		
AREA	273	195.83	0.7173	9.41	9.41	-188.56	22.72	<0.0001
SEASON	274	198.11	0.7230	8.69		-189.7	20.44	<0.0001
YEAR	270	210.48	0.7795	1.55		-195.88	8.07	0.2328
AREA +								
SEASON	271	182.48	0.6734	14.95	5.54	-181.88	13.35	0.0013
YEAR	267	184.45	0.6908	12.76		-182.87	11.38	0.0774
AREA+SEASON+								
YEAR	265	176.36	0.6655	15.95	1.00	-178.82	6.12	0.4096

FINAL MODEL RESULTS

Factors	**Akaike's information criterion**	**Schwarz's Bayesian criterion**	**-2 Res L**	**Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor** AREA	SEASON	YEAR
AREA+SEASON+YEAR	579	582	577	0.0001	0.0058	0.2496

% Difference: percent difference in deviance/df between the newly included factor and the previous factor entered into the model;
L: log likelihood; Chi Square: Pearson Chi-square statistic; Pr>Chi Square: significance level of the Chi-square statistic

Table 3. Deviance analysis tables showing the stepwise procedure used to develop the catch rate model for the **sandbar shark** in the South Carolina DNR longline survey. Proportion positive assumed a binomial error distribution, whereas positive catch rates assumed a Poisson distribution.

SCDNR LL

Proportion positive

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	725	627.82	0.8660			-313.91		
AREA	722	599.07	0.8297	4.19	4.19	-299.53	28.75	<0.0001
YEAR	719	597.62	0.8312	4.02		-298.81	30.20	<0.0001
SEASON	723	614.39	0.8498	1.87		-307.20	13.42	0.0012
AREA+								
YEAR	716	573.78	0.8014	7.46	3.27	-286.89	25.28	0.0003
SEASON	720	592.76	0.8233	4.93		-296.38	6.31	0.0427
AREA+YEAR+								
SEASON	714	570.16	0.7986	7.78	0.32	-285.08	3.62	0.1639

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: AREA	YEAR
AREA+YEAR	3661	3666	3659	<0.0001	0.0004

Positive catches

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	112	126.85	1.1326			-79.24		
SEASON	110	91.23	0.8294	26.77	26.77	-61.43	35.62	<0.0001
AREA	110	94.68	0.8607	24.01		-63.15	32.17	<0.0001
YEAR	106	112.89	1.0650	5.97		-72.26	13.96	0.0301
SEASON+								
AREA	108	85.02	0.7872	30.50	3.73	-58.32	6.21	0.0448
YEAR	104	85.82	0.8252	27.14		-58.72	5.41	0.4922
SEASON+AREA+								
YEAR	102	78.54	0.7701	32.01	1.51	-55.08	6.47	0.3722

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: SEASON	AREA	YEAR
SEASON+AREA+YEAR	250	252	248	0.0046	0.0204	0.2979

% Difference: percent difference in deviance/df between the newly included factor and the previous factor entered into the model;
L: log likelihood; Chi Square: Pearson Chi-square statistic; Pr>Chi Square: significance level of the Chi-square statistic

Table 4. Deviance analysis tables showing the stepwise procedure used to develop the catch rate model for the blacktip **shark** in the South Carolina DNR longline survey. Proportion positive assumed a binomial error distribution, whereas positive catch rates assumed a Poisson distribution.

SCDNR LL

Proportion positive

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	727	512.50	0.7050			-256.25		
YEAR	721	483.51	0.6706	4.88	4.88	-241.75	29.00	<0.0001
SEASON	725	495.17	0.6830	3.12		-247.58	17.33	0.0002
AREA	724	509.37	0.7036	0.20		-254.69	3.13	0.3717
YEAR+								
SEASON	719	471.84	0.6563	6.91	2.03	-235.92	11.66	0.0029
AREA	718	4787.11	0.6659	5.55		-239.06	5.39	0.1452
YEAR+SEASON+								
AREA	716	467.97	0.6536	7.29	0.38	-233.96	3.87	0.2754

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: YEAR	SEASON
YEAR+SEASON	3885	3890	3883	0.0013	0.0022

Positive catches

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	81	39.16	0.4834			-74.68		
YEAR	75	30.08	0.4011	17.03	17.03	-70.14	9.08	0.1692
SEASON	79	32.95	0.4170	13.74		-71.58	6.21	0.0448
AREA	79	38.66	0.4893	-1.22		-74.43	0.50	0.7779
YEAR+								
SEASON	73	26.18	0.3586	25.82	8.79	-68.19	3.90	0.1423
AREA	73	28.88	0.3956	18.16		-69.55	1.20	0.5492

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: YEAR
YEAR	151	154	149	0.0037

% Difference: percent difference in deviance/df between the newly included factor and the previous factor entered into the model;
L: log likelihood; Chi Square: Pearson Chi-square statistic; Pr>Chi Square: significance level of the Chi-square statistic

Table 5. Deviance analysis tables showing the stepwise procedure used to develop the catch rate model for**large coastal sharks** in the NEFSC bottom trawl survey. Proportion positive assumed a binomial error distribution, whereas positive catch rates assumed a Poisson distribution.

NEFSC Bottom Trawl

Proportion positive

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	24000	3811.29	0.1575			-1905.64		
DEPTHZONE	24000	3422.29	0.1414	10.22	10.22	-1711.15	389.00	<0.0001
SEASON	24000	3592.22	0.1485	5.71		-1796.11	219.07	<0.0001
YEAR	24000	2694.48	0.1529	2.92		-1847.24	116.81	<0.0001
DEPTHZONE +								
YEAR	24000	3264.48	0.1351	14.22	4.00	-1632.24	157.81	<0.0001
SEASON	24000	3310.77	0.1368	13.14		-1655.39	111.52	<0.0001
DEPTHZONE + YEAR								
SEASON	24000	3157.28	0.1307	17.02	2.79	-1578.64	107.19	<0.0001

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: DEPTHZONE	YEAR
DEPTHZONE+YEAR	128439	128447	128437	<0.0001	<0.0001

Positive catches

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	367	379.28	1.0335			-292.36		
DEPTHZONE	364	328.09	0.9013	12.79	12.79	-266.77	51.19	<0.0001
YEAR	336	311.57	0.9273	10.28		-258.51	67.71	0.0002
SEASON	365	354.05	0.9700	6.14		-279.75	25.22	<0.0001
DEPTHZONE +								
YEAR	333	256.79	0.7711	25.39	12.60	-231.12	71.3	<0.0001
SEASON	362	320.45	0.8852	14.35		-262.94	7.64	0.0219
DEPTHZONE + YEAR								
SEASON	331	251.49	0.7598	26.48	1.09	-228.47	0.07	0.0706

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: DEPTHZONE	YEAR	SEASON
DEPTHZONE+YEAR+ SEASON	849	853	847	<0.0001	<0.0001	0.0574

% Difference: percent difference in deviance/df between the newly included factor and the previous factor entered into the model;
L: log likelihood; Chi Square: Pearson Chi-square statistic; Pr>Chi Square: significance level of the Chi-square statistic

Table 6. Deviance analysis tables showing the stepwise procedure used to develop the catch rate model for the **sandbar shark** in the NEFSC bottom trawl survey. Proportion positive assumed a binomial error distribution, whereas positive catch rates assumed a Poisson distribution.

NEFSC Bottom Trawl

Proportion positive

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	17000	2214.82	0.1288			-1107.41		
DEPTHZONE	17000	2069.04	0.1203	6.60	6.60	-1034.52	145.77	<0.0001
YEAR	17000	2118.96	0.1234	4.19		-1059.48	95.86	<0.0001
SEASON	17000	2183.63	0.1270	1.40		-1091.82	31.18	<0.0001
DEPTHZONE +								
YEAR	17000	1951.12	0.1137	11.72	5.12	-975.56	117.92	<0.0001
SEASON	17000	2063.54	0.1200	6.83		-1031.77	5.50	0.0638

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: DEPTHZONE	YEAR
DEPTHZONE+YEAR	127866	127874	127864	<0.0001	<0.0001

Positive catches

Factors	d.f.	Deviance	Deviance/df	% Reduction in deviance/df	% Difference	L	Chi Square	Pr>Chi Square
NULL	203	168.40	0.8295			-181.11		
YEAR	174	111.24	0.6393	22.93	22.93	-152.53	57.15	0.0014
DEPTHZONE	200	135.12	0.6756	18.55	18.55	-164.47	33.28	<0.0001
SEASON	201	148.54	0.7390	10.91		-171.18	19.85	<0.0001
YEAR+								
DEPTHZONE	171	71.69	0.4192	49.46	26.53	-132.76	39.55	<0.0001
SEASON	172	84.68	0.4923	40.65		-139.25	26.57	<0.0001
YEAR + DEPTHZONE +								
SEASON	169	71.16	0.4211	49.23	-0.23	-132.49	0.53	0.7681

FINAL MODEL RESULTS

Factors	Akaike's information criterion	Schwarz's Bayesian criterion	-2 Res L	Significance (Pr>Chi square) of theType 3 test of fixed effects for each individual factor: YEAR	DEPTHZONE
YEAR+DEPTHZONE	363	366	361	<0.0001	<0.0001

% Difference: percent difference in deviance/df between the newly included factor and the previous factor entered into the model;
L: log likelihood; Chi Square: Pearson Chi-square statistic; Pr>Chi Square: significance level of the Chi-square statistic

Table 7. Trends in catch rates of large coastal sharks. Slopes and standard errors (SE) of the slopes were obtained from linear regressions of relative catch rates on year. Slopes significantly different from 0 are denoted as * (5% level), ** (1% level), and *** (0.1% level) for quick identification.

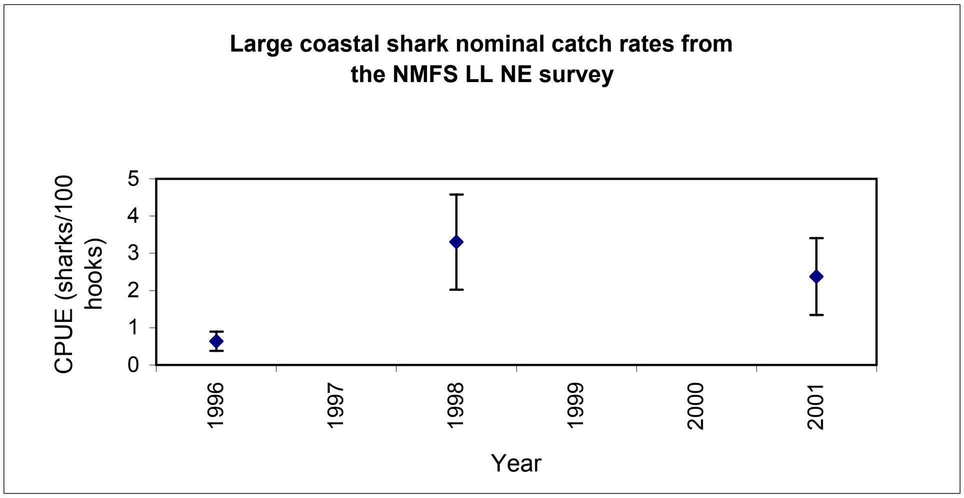
Series	**Sample size**	**Years**	**Slope**	**SE**	**P value**	**r^2**
Large coastal						
Shark Observer	8	1994-2001	0.1057**	0.0263	0.0069	0.73
NMFS LL NE [1,2]	3	1996-2001	0.0442	0.0177	0.8620	0.86
SC LL[1]	7	1995-2001	0.0169	0.0217	0.4711	0.11
NEFSC Trawl	29	1972-2000	-0.0581**	0.0193	0.0055	0.25
MRFSS1 [1]	13	1981-1993	-0.0299**	0.0074	0.0019	0.60
MRFSS1 [1]	8	1994-2001	-0.0315*	0.0125	0.0457	0.51
MRFSS2 [1]	13	1981-1993	-0.0331**	0.0098	0.0063	0.51
MRFSS2 [1]	7	1994-2000	0.0200	0.0089	0.0739	0.50
Sandbar						
Shark Observer	8	1994-2001	0.0943	0.0570	0.1489	0.31
NMFS LL NE [1,2]	3	1996-2001	0.0832	0.1325	0.6430	0.28
SC LL[1]	7	1995-2001	0.0449	0.0446	0.3597	0.17
NEFSC Trawl [2]	28	1972-2000	-0.0284	0.0223	0.2152	0.06
MRFSS1 [1]	13	1981-1993	-0.0541*	0.0208	0.0244	0.38
MRFSS1 [1]	8	1994-2001	-0.0095	0.0369	0.8055	0.01
MRFSS2 [1]	13	1981-1993	-0.0647**	0.0167	0.0026	0.58
MRFSS2 [1]	7	1994-2000	0.0583	0.0735	0.4635	0.11
Blacktip						
Shark Observer [1]	8	1994-2001	-0.0179	0.0616	0.7817	0.01
NMFS LL NE [1,2]	3	1996-2001	0.0810	0.1235	0.6305	0.30
SC LL[1]	7	1995-2001	-0.1060	0.0524	0.0989	0.45
MRFSS1 [1]	13	1981-1993	0.0200	0.0155	0.2233	0.13
MRFSS1 [1]	8	1994-2001	-0.0204	0.0204	0.3563	0.14
MRFSS2 [1]	13	1981-1993	0.0123	0.0131	0.3672	0.07
MRFSS2	7	1994-2000	0.0175	0.0984	0.8656	0.01
Dusky						
Shark Observer [1]	8	1994-2001	0.0269	0.0431	0.5551	0.06
NMFS LL NE [2]	3	1996-2001	0.3318*	0.0210	0.0403	0.99
MRFSS1 [1]	13	1981-1993	-0.0356	0.0193	0.0923	0.24
MRFSS1 [1]	8	1994-2001	-0.0822	0.0339	0.0513	0.49
MRFSS2 [1]	13	1981-1993	-0.0308	0.0234	0.2145	0.14
MRFSS2	7	1994-2000	0.0683	0.0889	0.4775	0.10

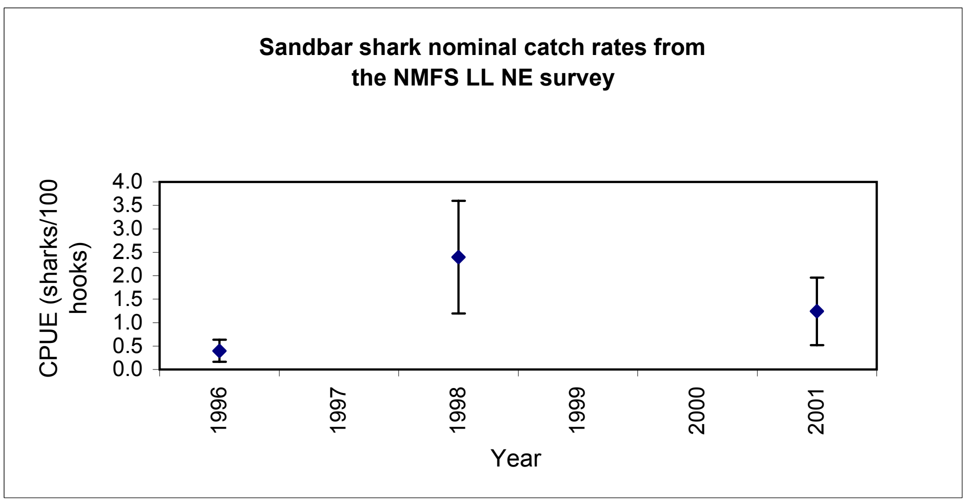
Table 7. (continued).

Series	Sample size	Years	Slope	SE	P value	r^2
Tiger						
Shark Observer [1]	8	1994-2001	0.0672*	0.0256	0.0394	0.53
NMFS LL NE [2]	3	1996-2001	0.1876	0.1187	0.3592	0.71
Hammerheads						
MRFSS1	13	1981-1993	-0.1093	0.0542	0.0687	0.27
MRFSS1	8	1994-2001	-0.1909	0.0803	0.0549	0.48
MRFSS2	13	1981-1993	-0.1351**	0.0351	0.0027	0.57
MRFSS2 [1]	7	1994-2000	-0.1023*	0.0254	0.0101	0.76
Bull						
MRFSS1	13	1981-1993	-0.1224	0.0647	0.0853	0.24
MRFSS1	8	1994-2001	-0.0594	0.1164	0.6282	0.04
MRFSS2	13	1981-1993	-0.0715	0.0663	0.3043	0.09
MRFSS2 [1]	7	1994-2000	-0.0663	0.0368	0.1315	0.39
Scalloped hammerhead						
NMFS LL NE [1,2]	3	1996-2001	0.2750*	0.0163	0.0377	0.99
Silky						
NMFS LL NE [1,2]	3	1996-2001	0.0292	0.0912	0.8028	0.09

[1] Indicates that the dependent variable (catch rate) was log-transformed.
[2] Indicates that there are missing data for some years.

Figure 1. Nominal catch rates of large coastal sharks, sandbar shark, and blacktip shark from NMFS LL NE survey data. CPUE is the number of sharks caught per 100 sharks. Vertical bars are 95% confidence limits.





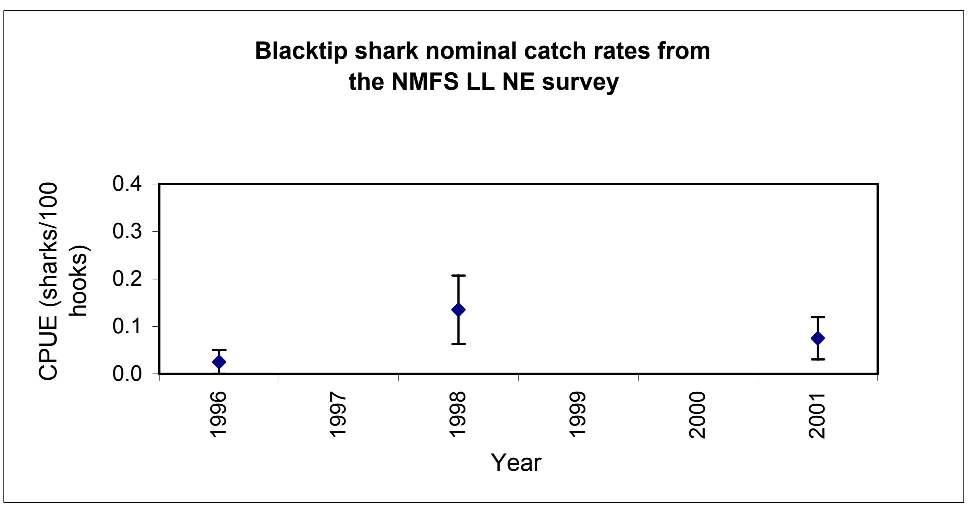
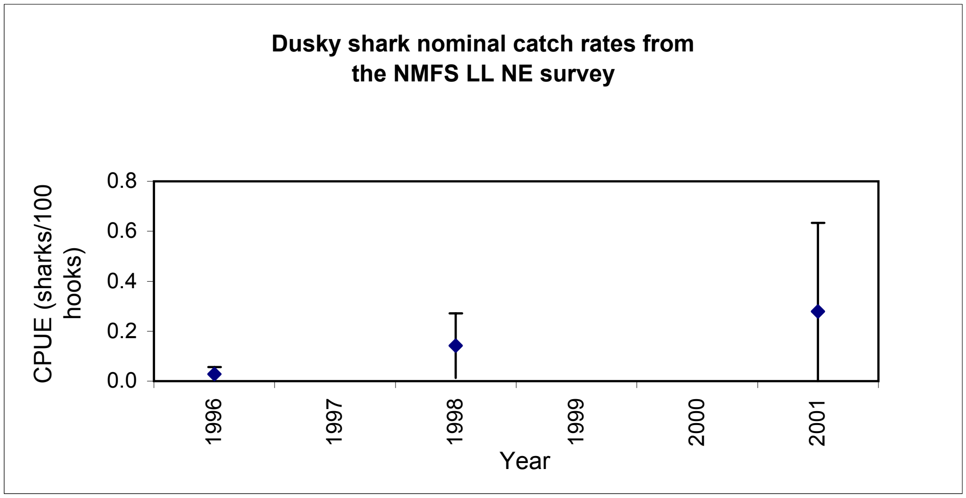
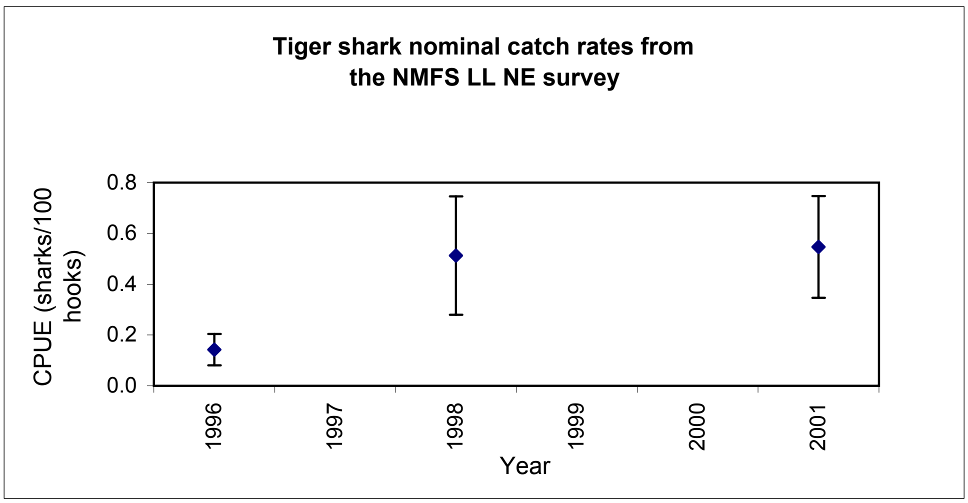


Figure 2. Nominal catch rates of dusky, tiger, scalloped hammerhead, and silky shark from NMFS LL NE survey data. CPUE is the number of sharks caught per 100 sharks. Vertical bars are 95% confidence limits.





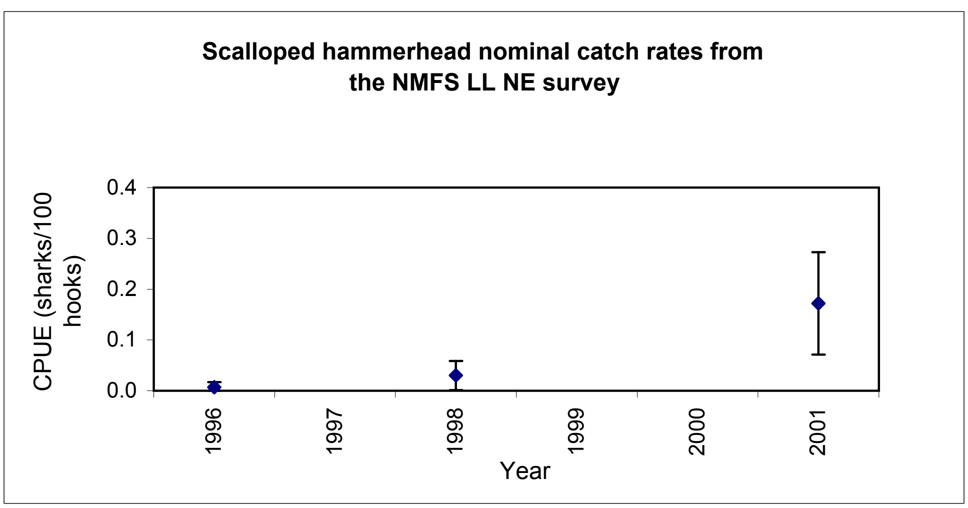


Figure 2 (continued). Nominal catch rates of dusky, tiger, scalloped hammerhead, and silky shark from NMFS LL NE survey data. CPUE is the number of sharks caught per 100 sharks. Vertical bars are 95% confidence limits.

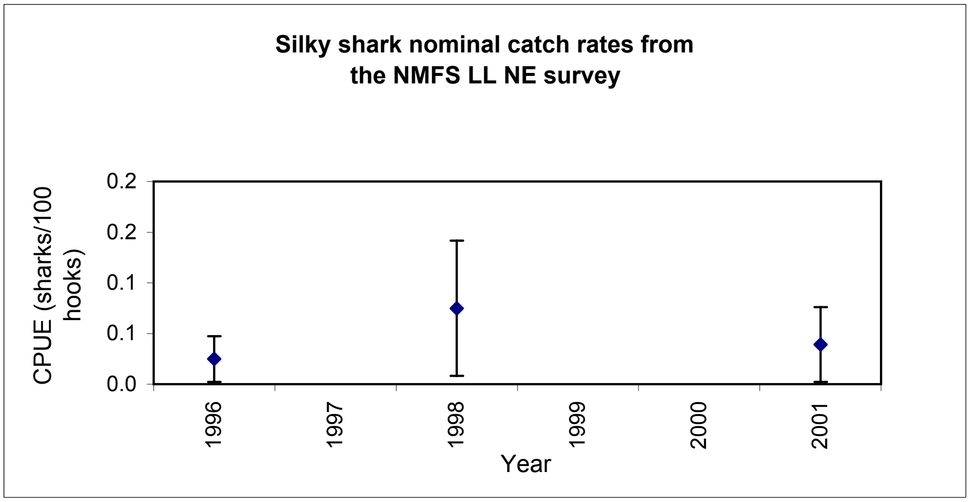
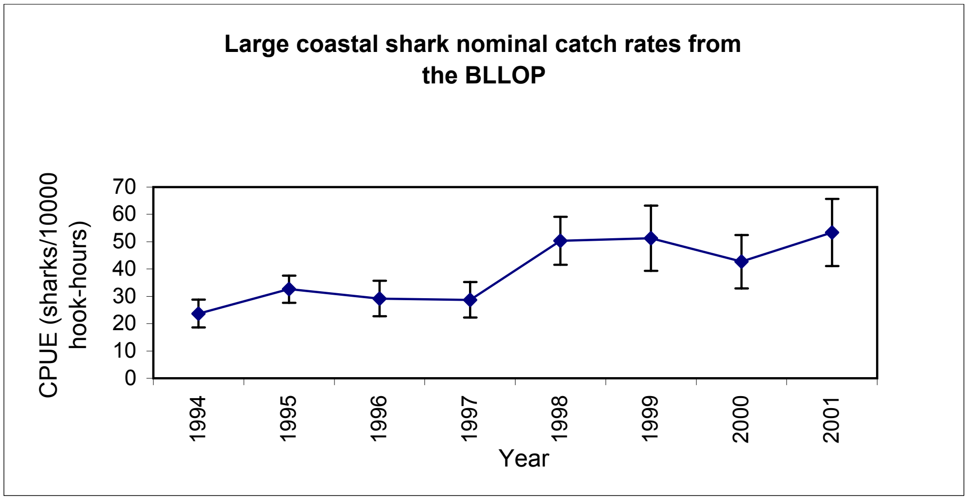
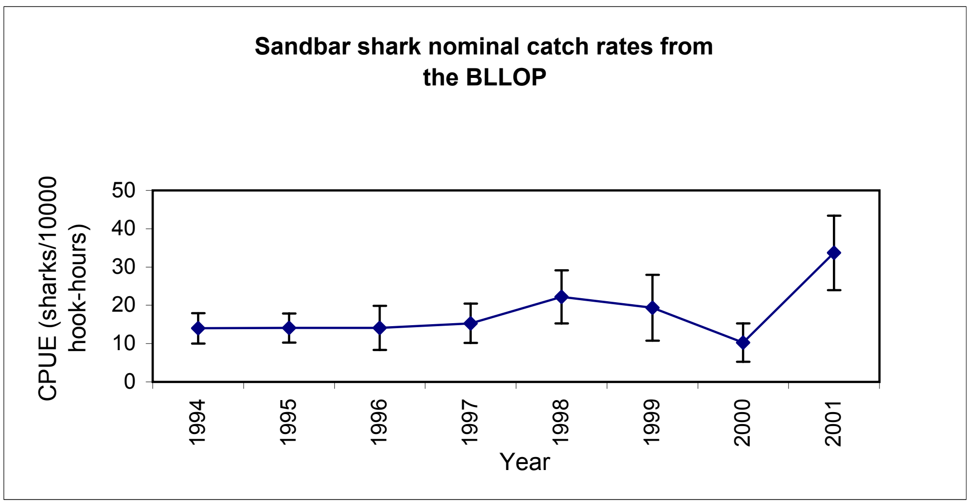


Figure 3. Nominal catch rates of large coastal, sandbar, and blacktip sharks from the directed shark fishery Bottom Longline Observer Program. CPUE is the number of sharks caught per 10000 hookhours. Vertical bars are 95% confidence limits.





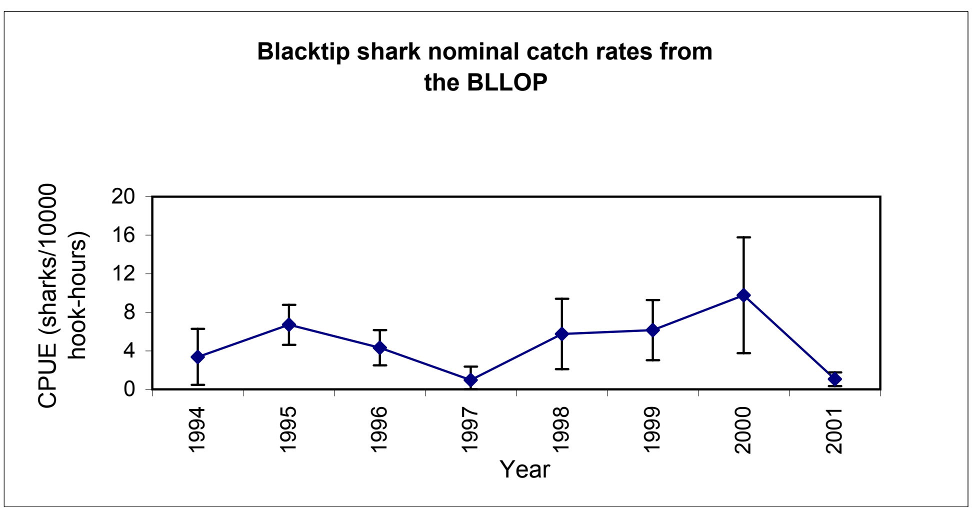
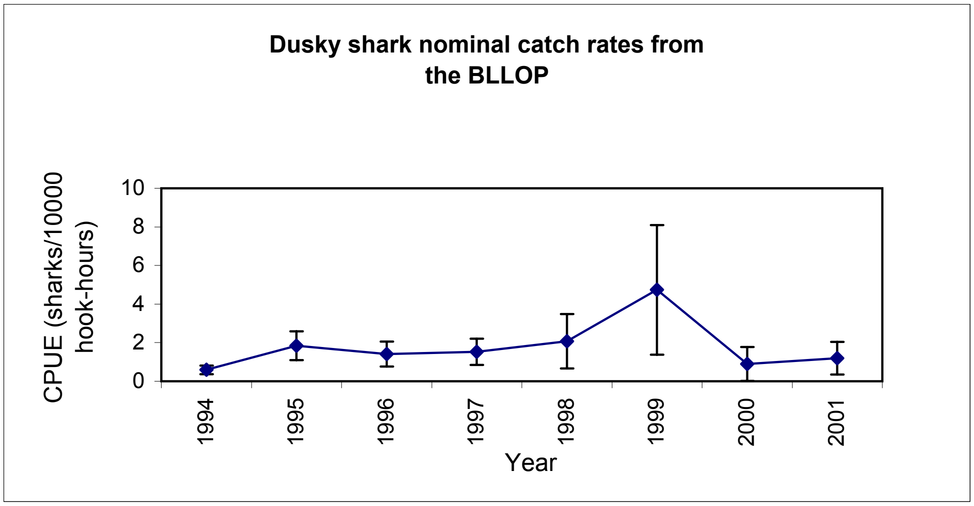


Figure 4. Nominal catch rates of large coastal, sandbar, and blacktip sharks from the directed shark fishery Bottom Longline Observer Program. CPUE is the number of sharks caught per 10000 hookhours. Vertical bars are 95% confidence limits.



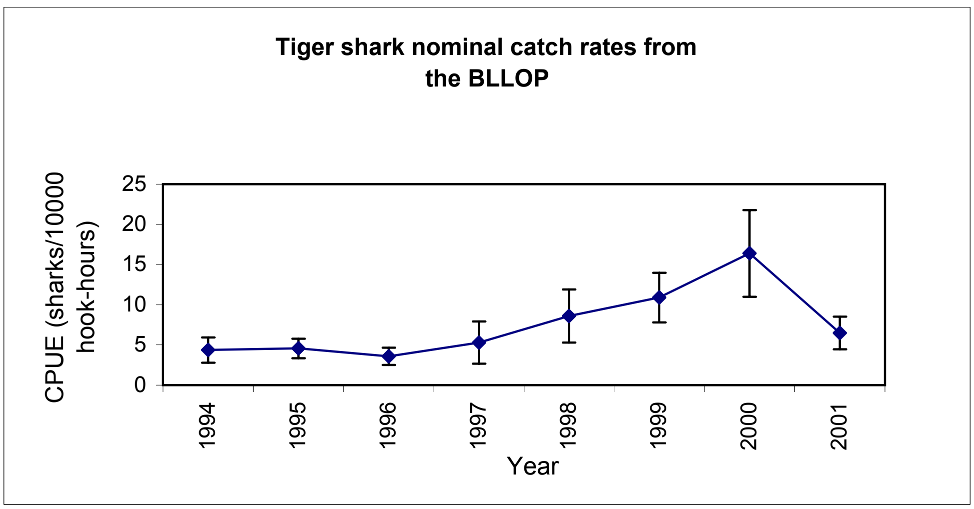
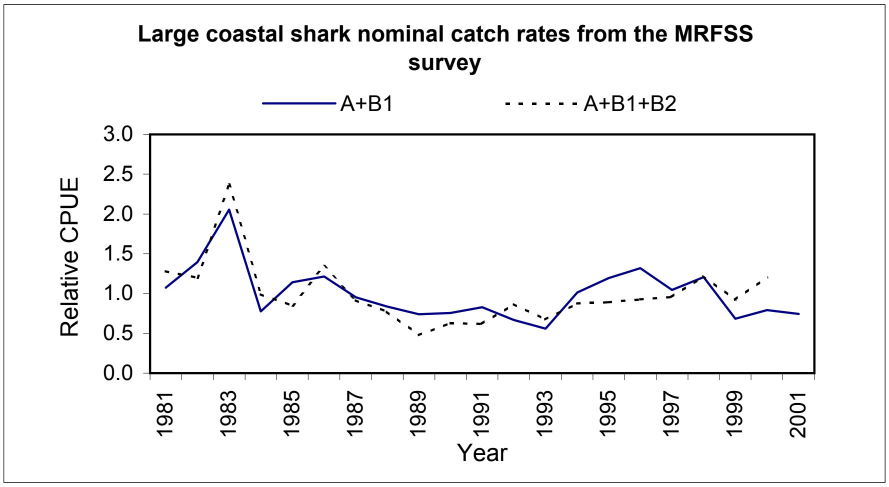
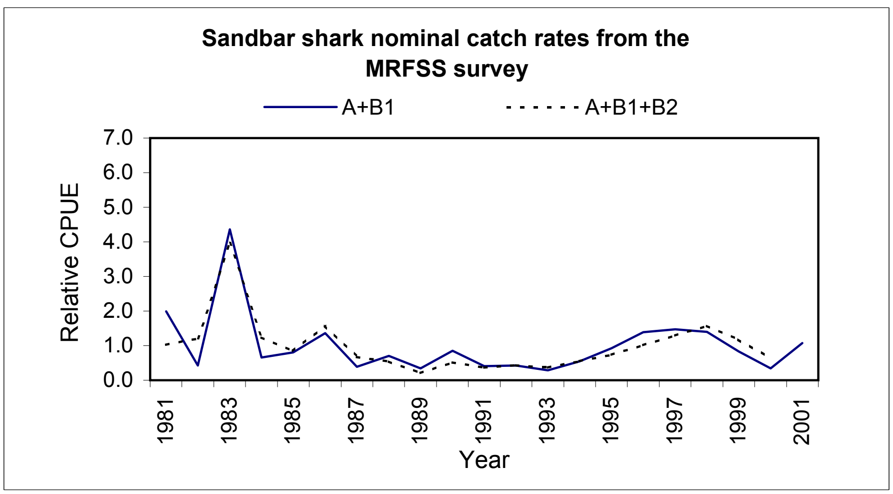


Figure 5. Relative nominal catch rates of large coastal sharks, sandbar shark, and blacktip shark from MRFSS survey data for 1981-1993 (left) and 1994-20001 or 2000 (right). CPUE is the total number of sharks caught per year divided by total effort (angler trips) per year. The solid line denotes type A+B1 catches (A:catch available for identification;B1: unavailable catch used for bait, filleted, discarded dead or other) and the broken line represents type A+B1+B2 catches (B2: unavailable catch released alive).





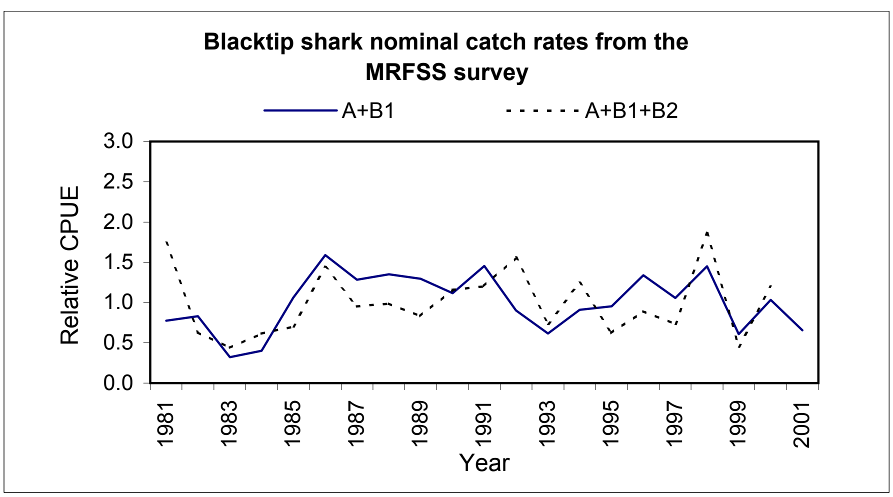
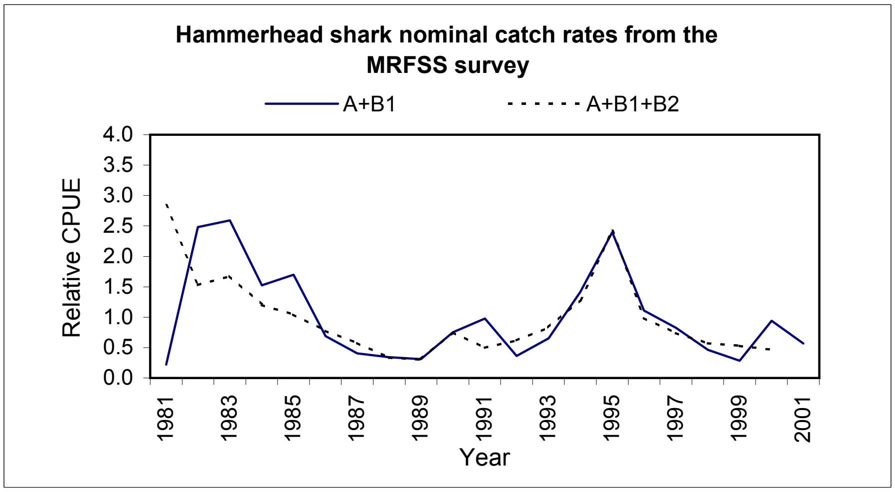
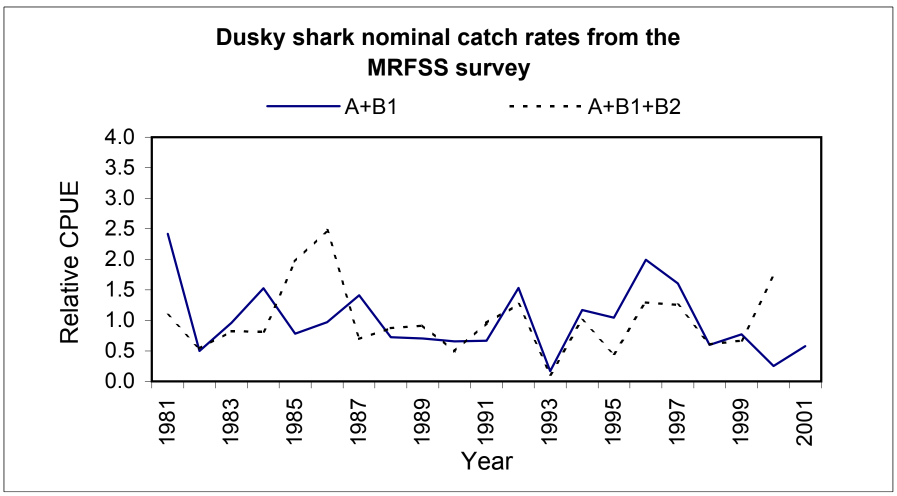


Figure 6. Relative nominal catch rates of hammerhead (genus) sharks, dusky, and bull shark from MRFSS survey data. CPUE is the total number of sharks caught per year divided by total effort (angler trips) per year. The solid line denotes type A+B1 catches (A:catch available for identification; B1: unavailable catch used for bait, filleted, discarded dead or other) and the broken line represents type A+B1+B2 catches (B2: unavailable catch released alive).





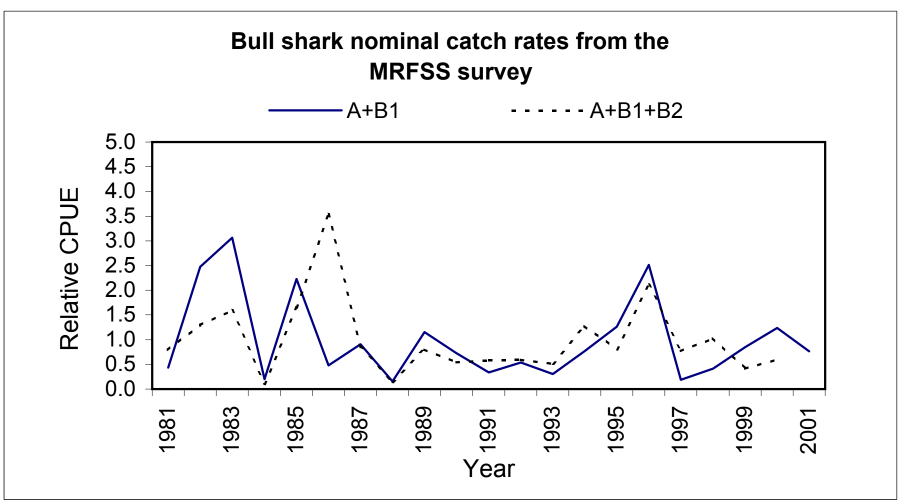
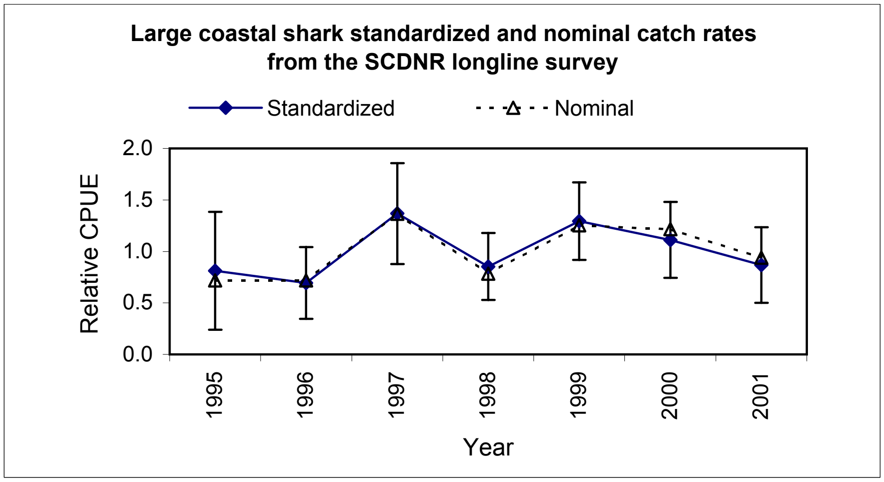
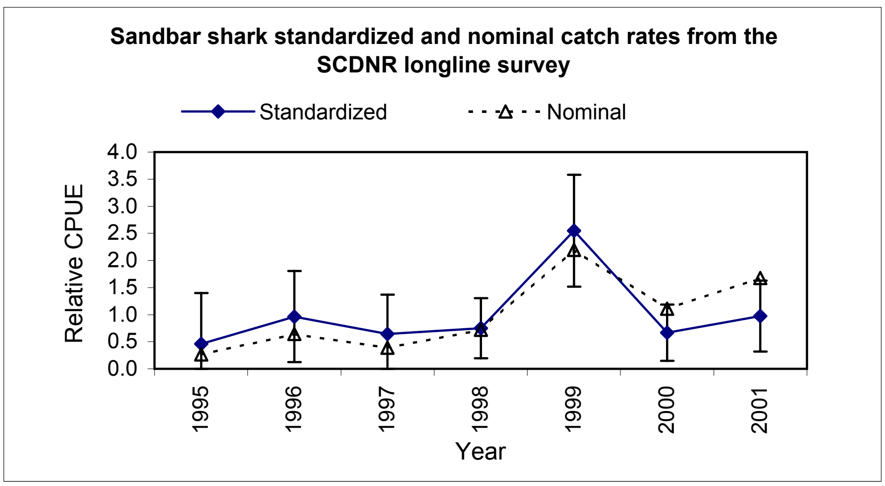


Figure 7. Relative nominal and standardized catch rates of large coastal sharks, sandbar shark, and blacktip shark from SCDNR longline survey data. CPUE is the number of sharks caught per 120 hooks per 0.75 hours. The broken line denotes the nominal average CPUE and the solid line represents the standardized CPUE (with lower and upper 95% confidence limits).





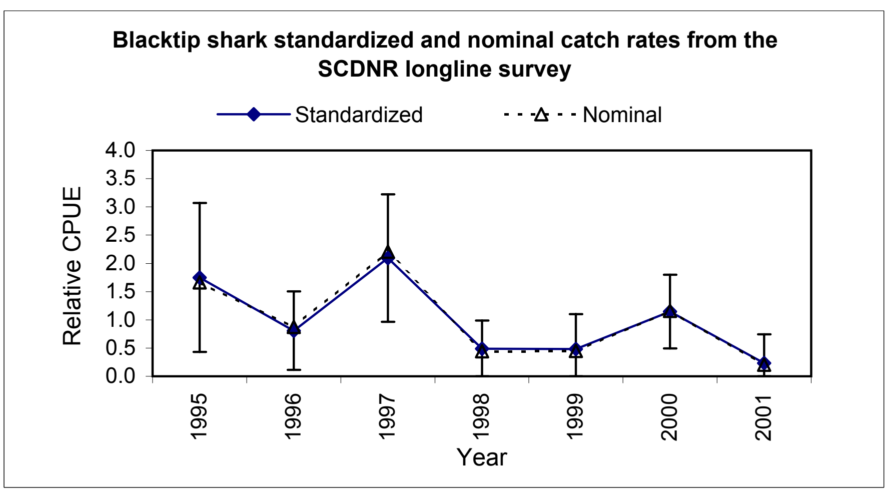


Figure 8. Relative nominal and standardized catch rates of large coastal sharks and sandbar shark from NEFSC bottom trawl survey data. CPUE is the number of sharks caught per 30-minute tow. The broken line denotes the nominal average CPUE and the solid line represents the standardized CPUE (with lower and upper 95% confidence limits).